Courtesy of SAFS project

Jack Kelly Clark

An in-row cultivator uproots weeds in the organic corn plots. The torsion rods loosen soil in the crop row, dislodging small weeds without injury to the deep-rooted corn crop.

In low-input and organic systems . . .

Researchers find short-term insect problems, long-term weed problems

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The conversion from conventional to low-input or organic crop production requires changes in pest control tactics. In a 5-year study, abundance of most pests did not change dramatically between conventional and low-input or organically managed systems, with a few notable exceptions. Organic and low-input plots suffered significantly greater damage from tomato fruitworm in 1989 and stink bugs in 1992. The major long-term effect has been on weeds. Weed control methods differ among the systems and have resulted in more barnyardgrass in low-input and organic systems and field bindweed and nightshade in conventional systems.

Increasing numbers of growers are considering changing from conventional to low-input or organic farming systems as political, economic and biological pressures increase. A major obstacle in making this transition has been a lack of information on pest biology, occasional outbreaks of unexpected pests that are difficult to manage with organic practices and lack of economic, nonchemical control options for some pest species.

The crop being grown, cultural practices used in that crop, prior cropping history, neighboring crops and pest control methods employed all influence pest species' abundance and composition. Each crop typically attracts its own subset of pest species. For example, both corn and tomatoes are attacked by cutworms and wireworms, but only corn is attacked by corn smut, and only tomato by black mold. The subset of pests affecting a certain crop may be limited by the time period in which that crop is grown; for example, processing tomatoes are generally planted earlier than corn and may be impacted by a different species guild at that time. However, since the crop affects pest species and abundance, the first crop in a rotation can also influence the entire rotation by increasing the weed seed, insect and plant parasitic nematode populations or inoculum level of pests and pathogens common to subsequent crops as well.

Cultural practices used in a crop or cropping system also can influence pest populations. For example, legume cover crops are beneficial in providing nitrogen for the succeeding cash crop, but they also modify the microenvironment, potentially influencing pest populations. Seed corn maggot populations may be enhanced with increased moisture and humidity associated with a winter cover crop, while frequent tillage or host-free periods reduce their abundance. Cover crops require incorporation prior to planting of the subsequent crop. This may result in changes in crop planting time, potentially exposing the crop to a different subset of pests.

Pest control methods used in different farming systems vary in their effectiveness and in the range of species they control. Tillage, used more frequently in low-input and organic farming systems, favors annual weeds capable of reproducing in a short period of time or perennials that regrow after tillage and benefit from reduced competition. Frequent tillage also helps to spread weed seed, perennial vegetative propagules and disease inoculum. Herbicides or insecticides vary in effectiveness between species, allowing those not controlled to proliferate. This effect is especially pronounced when the same material is used repeatedly and can also lead to pest resistance.

The shift from conventional to low-input or organic farming systems necessitates the modification of cultural practices and pest control methods. Although it is recognized that pest populations will change in this transition, the species composition, diversity and abundance that result are not known. In this long-term study, the Sustainable Agriculture Farming Systems project at UC Davis, four farming systems were compared. Each system differed in the cultural practices and pest control methods used. The objectives of this study with regard to pest biology and management were to assess, over time, the relative abundance and species composition of pests in each of the four farming systems. Additionally, practical cultural modifications implemented in low-input or organic systems were compared to assess their influence on pests.

Monitoring practices

The cropping systems were established in 1989 (for details, see pp. 14–19). Individual plots were approximately one-third acre in size and replicated four times. All systems were managed using "best farmer practices" recommended by farmers and farm advisors who were members of the project team. Management decisions were based on cost of control, potential loss and environmental or social implications appropriate to the system (see tables 1 and 2). Pest monitoring and treatment decisions were made according to the UC Integrated Pest Management Project (IPM) guidelines. California Certified Organic Farmer (CCOF) guidelines were adhered to in the organic plots. Low-input treatments used a combination of CCOF and UC IPM guidelines, attempting to reduce off-farm inputs.

Insect monitoring varied by crop. Processing tomato seedlings were monitored for evidence of feeding by flea beetles, cutworms and wireworms by recording the number of damaged plants per 25 consecutive plants in the third row of each treatment replicate border. After small green fruit appeared, we picked 30 leaves (the leaf below the highest open flower) per plot, and counted the number of fruitworm eggs, parasitized eggs and leaves with potato aphids and parasitized aphids. Each week after green tomatoes reached 1 inch in diameter, we randomly picked 50 tomato fruit per plot and examined them for fruitworm damage.

Also at this time, we examined the base of the plants and lower leaves for bronzing by russet mites and applied sulfur treatments if mite damage was detected. To determine the presence of stink bugs, we placed trays below the foliage of three tomato plants and shook the plants. The trays and the areas under the trays were then examined for stink bugs

Seedling corn was visually examined for signs of feeding by seed corn maggots, cutworms and wireworms. Spider mites and aphids were monitored by picking 40 lower leaves (not senescing) per plot every 2 weeks and recording the number of leaves with spider mites, mite predators, aphids and parasitized aphids. Once tassels and silk were present, the number of ears with corn earworm were recorded each week until the dent stage.

In beans, safflower and wheat, insects were not monitored on a regular basis. The plots were examined for the presence of arthropods after seedling emergence. More intensive monitoring was conducted when pest presence was detected.

We made an annual inventory of all nematode species present and the populations of each species in each plot. Soil samples were taken to a depth of 30 centimeters, with 20 to 30 soil cores pooled in each plot. Nematodes were extracted from a 300- to 400-cm^3 subsample of soil by elutriation and sugar centrifugation. For each sample, the total number of nematodes was counted and a subset of 200 to 300 individuals identified by genus (and species where possible). The number of each nematode type per liter of soil was calculated for each plot. The species of nematodes were categorized according to their feeding habits.

Plant diseases were visually evaluated in each plot weekly. Detailed assessments of Rhizoctonia and Verticillium presence in soil samples were made yearly.

Weed cover was visually assessed on each plot monthly, with predominant weed species noted. Measurements were generally made just prior to cultivation or herbicide treatment. Biomass measurements were made in each plot at crop harvest by clipping all weeds at ground level in a randomly placed 0.25-m^2 quadrat. We generally took four biomass samples per plot, and never less than two. Biomass samples were separated by species, dried and weighed.

Control treatments

Insects. As might be anticipated, little difference in abundance of highly mobile pests was seen among systems (table 3), as the relatively small plots allowed migration between plots. With only a few exceptions, most differences between systems appeared to be due to treatments applied for control. There were differences in abundance of some species across all treatments between years.

In processing tomatoes, an application of sulfur (Thiolux) was applied to all plots in the 1989, 1990 and 1991 sea-

TABLE 1. Pest management and inputs per acre for alternative systems*			
		Organic and low input†	**Conventional 2- and 4-Year**
WEEDS			
Tomato	1989	Cultivate‡ — 8X Hand hoe — 3X (22.2 hours)	Cultivate — 8X Hand hoe — 3X (14.8 hours) Preplant Devrinol @ 0.2 gal Layby Treflan @ 1.45 pint
	1990	Cultivate — 6X Hand hoe — 2X (43.9 hours)	Cultivate — 4X Hand hoe — 2X (7.4 hours) Preplant Devrinol @ 0.2 gal Layby Treflan @ 1 pint
	1991	Cultivate — 7X Hand hoe — 3X (64.5 hours)	Cultivate — 4X Hand hoe — 3X (21.5 hours) Preplant Roundup @ 1.5 pint Preplant Devrinol @ 0.2 gal Layby Treflan @ 1 pint
	1992	Cultivate — 3X Hand hoe — 3X (**O:** 32.0 hours, **LI:** 28.0 hours)	Cultivate — 3X Hand hoe — 3X (10.4 hours) Fallow Roundup @ 1.7 pint Preplant Devrinol @ 0.36 pint
Safflower	1989	Cultivate — (**O**:4X **LI**: 5X) **LI only:** Fallow Roundup @ 1.5 pint	Cultivate — 4X Fallow Roundup @ 1.5 pint Preplant Treflan @ 1.5 pint
	1990	Cultivate — 1X	Cultivate — 2X Fallow Roundup @ 1.3 pint Preplant Treflan @ 1.4 pint
	1991	Cultivate — 1X	Cultivate — 1X Fallow Roundup @ 1.5 pint Preplant Treflan @ 1.5 pint
	1992§	Cultivate — 7X Mow weeds — 2X	Cultivate — 1X Fallow Roundup @ 1.7 pint Preplant Treflan @ 1.5 pint
Corn	1989	Cultivate — (**O**:4X **LI**: 3X) **LI only:** Fallow Roundup @ 1.5 pint Mow weeds — 1X **LI only:** Layby Weedar @ 1 pint & Banvel @ 0.5 pint	Cultivate — 5X Fallow Roundup @ 1.5 pint Mow weeds — 1X Layby Weedar @ 1 pint & Banvel @ 0.5 pint Preplant Dual @ 2 pint
	1990	Cultivate — 1X Layby Weedar @ 1 pint & Banvel @ 0.5 pint	Cultivate — 1X Layby Weedar @ 1 pint Fallow Roundup @ 1.5 pint Preplant Dual @ 2 pint
	1991	Cultivate — 1X	Cultivate — 1X Fallow Roundup @ 1.5 pint Preplant Dual @ 2 pint
	1992	Cultivate — 3X **LI only :** Layby Weedar @ 2 pint	Cultivate — 1X Fallow Roundup @ 1.7 pint Preplant Dual @ 2.5 pint
Winter legume/ wheat	1989	Cultivate — (**O**:4X **LI**: 1X) **LI only:** Preplant Dual @ 2 pint & Prowl @ 2 pint	Postplant Bronate @ 2 pint
	1990	——	Postplant Bronate @ 2 pint
	1991	——	Postplant Bronate @ 2 pint
	1992	——	Postplant Hoelon @ 1 pint & MCPA @ 1 pint
Beans¶	1990	Cultivate — 1X	Cultivate — 1X Preplant Treflan @ 1 pint
	1991	Cultivate — 2X	Cultivate — 1X Preplant Treflan @ 1 pint
	1992	Cultivate — 3X	Cultivate — 3X Preplant Treflan @ 1.5 pint

(cont. on p. 30)

(cont. from p. 29)

TABLE 1. Pest management and inputs per acre for alternative systems*

		Organic and low input†	Conventional 2- and 4-Year
INSECTS			
Tomato	1989	Insecticide/acaricide Thiolux @ 5 lb & (**O:** Safer Soap @ 2 gal, **LI:** Thiodan @ 0.33 gal)	Insecticide/acaricide Thiodan @ 0.33 gal & Thiolux @ 5 lb Insecticide Pydrin @ 0.8 pint
	1990	Acaricide Thiolux @ 40 lb Insecticide **LI only:** Pydrin @ 0.08 gal **O only:** Dipel @ 1 lb	Acaricide Thiolux @ 40 lb Insecticide Pydrin @ 0.08 gal
	1991	Acaricide Thiolux @ 10 lb Insecticide Dipel @ 1 lb	Acaricide Thiolux @ 10 lb Insecticide Asana @ 9.6 oz
	1992	—	Insecticide Asana @ 9.6 oz
Corn	1989	—	Acaricide Comite @ 2 pint
	1990	—	Acaricide Comite @ 2.5 pint
DISEASE			
Tomato	1989	**LI only:** Fungicide Dithane @ 3 lb	Fungicide Dithane @ 3 lb & Bayleton @ 0.25 lb

*All inputs are in units of material per acre.
†Inputs are for both systems unless otherwise indicated. **O** = organic and **LI** = low-input
‡Some operations listed as cultivate may be used primarily for reasons other than weed management, but are included here to indicate that they have a control effect on weeds.
§Low-input and organic safflower were replanted to beans.
¶Beans not planted in 1989.

sons when russet mites were first detected. Russet mites are common pests of California processing tomatoes, and over half of all commercial fields in California receive applications annually.

In 1989 two treatments were made to conventional plots to control beet armyworm and tomato fruitworm. In 1990 all processing tomato systems except the organic system received a single treatment for tomato fruitworm control. In 1991 all systems received a single treatment for fruitworm control. No fruitworm control was needed in 1992, probably a result of the earlier harvest date relative to previous years. When treatment for tomato fruitworm was needed, *Bacillus thuringiensis* (Dipel) was used in the organic and occasionally the low-input plots. Fenvalerate (Pydrin) or esfenvalerate (Asana) was used in the conventional plots and occasionally in the low-input plots. In 1989 significantly more ($P < 0.05$) tomato fruitworm damage was found in the organic treatment ($x = 0.94\%$) than in the low-input ($x = 0.51\%$), conventional 2-year ($x = 0.21\%$) or conventional 4-year ($x = 0.28\%$) treatments. No significant differences were observed among the farming systems in other years.

We treated all the plots for potato aphids in 1989; applying insecticidal soap (Safer Soap) to the organic plots and endosulfan (Thiodan) to the other systems. The endosulfan (Thiodan) treatment resulted in significantly lower aphid abundance relative to the soap treatment.

The conventional plots were treated once for stink bugs in 1992. No application was made to either the organic or low-input plots because no organically acceptable pesticides registered for processing tomatoes are known to be effective against stink bugs. Stink bug damage at harvest was much higher in the organic ($x = 10.64\%$) and low-input ($x = 21.43\%$) treatments than in either the conventional 2-year ($x = 6.95\%$) or 4-year ($x = 5.78\%$) treatments. This damage would not have been important if the tomatoes were intended for paste, but would have been a serious problem for whole pack because it causes localized internal tissue to harden and discolor around the area of the bug feeding.

Damage by seedling pests has been very low in all plots, and no treatments have been applied for control. We have noted that seedling damage by cutworms has been somewhat higher in the organic and low-input treatments in which processing tomatoes were preceded by a vetch cover crop.

In the first 2 years of the study (1989 and 1990), we applied the acaricide propargite (Comite) to control spider mites in the conventionally grown corn. Seed corn maggot has been a serious pest in organic and low-

TABLE 2. Pesticide use (lb active ingredient/ac) in each system by crop, 1989 to 1993

Crop	Target pest	Organic	Low Input	Conventional 2-year	Conventional 4-year
Tomatoes	Weeds	0.00	0.00	8.58	8.58
	Insects	9.23	20.03	21.58	21.58
	Disease	2.25	0.00	4.62	4.62
Safflower	Weeds	0.75	0.00	—*	7.41
Corn	Weeds	5.00	0.00	—	13.60
	Insects	0.00	0.00	—	3.65
Winter legume/ wheat	Weeds	0.00	0.00	4.88	4.88
Beans	Weeds	0.00	0.00	—	2.56
Total lb ai/ac	Weeds	5.75	0.00	26.92†	37.03
	Insects	19.23	20.03	43.16†	25.23
	Disease	2.25	0.00	9.24†	4.62
Total		27.23	20.03	79.32	66.88

*— = not applicable. Only tomatoes and wheat were grown in the 2-year rotation.
†Total pesticide use is doubled to represent an area equal to what is used in other systems.

input safflower and corn in the past 2 years. In 1992 maggot damage to safflower stands forced replanting, and about 25% of corn seeds were damaged. Seed corn maggot is known to be most severe in fields that have received applications of manure or contain high amounts of organic matter and in which the soil is sufficiently moist. It is our experience that seed corn maggot should be considered a potential problem whenever a host crop is planted in close rotation with a fall or winter cover crop.

Nematodes. Approximately 30% of the nematodes extracted from soils at the field site over 4 years of the project have been parasites of plants. The most prevalent species were lesion nematodes *(Pratylenchus thornei)*, stunt nematodes *(Tylenchorhynchus/Merlinius)*, pin nematodes *(Paratylenchus* spp.*)* and dagger nematodes *(Xiphinema americanum)*. Of these, the lesion nematode was consistently present following beans and cereals, which are major hosts of this species. It was not detected at levels that would be considered damaging to those crops. *Pratylenchus thornei* is not a parasite of tomato, and its numbers declined during the tomato crop in the rotation sequence. The stunt, pin and dagger nematodes may be parasites of vetch and other leguminous cover crops, but soil temperatures during the fall and winter niche for those crops are probably not conducive to large nematode population increases. Root-knot nematodes *(Meloidogyne* spp.*)* occurred occasionally in the plots, but since the processing tomato varieties grown were root-knot resistant, these nematodes usually occurred in low numbers.

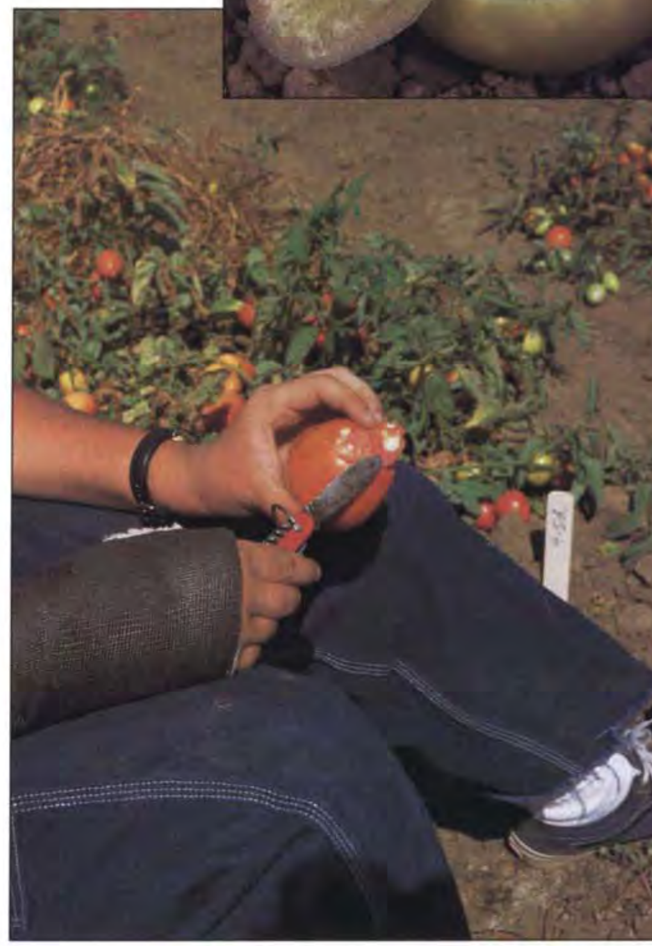
Prior to 1988, the experimental site was a patchwork of smaller research plots for studies on wheat, alfalfa and beans, all managed conventionally. There was considerable variability among nematode species occurring in the plots at the initial 1988 nematode inventory. In the two conventional farming systems, the total numbers of all nematodes in the soil increased between 1988 and 1992, with plant parasitic species representing an increasingly larger proportion of the community. In the low-input and organic systems, the total number of all nematodes, including the plant parasites, decreased in the top 30 centimeters of soil.

There were many factors driving the population dynamics of plant parasitic nematodes under the different farming systems. Interestingly, the diversity of crops in the rotation sequence in all farming systems seemed to be the basis for the stability of population densities of all plant parasitic nematode species. None appeared to be approaching damaging levels at this stage.

Disease. Verticillium appeared to increase in soils on the conventional 2-year rotation plots. The presence of a suitable host, processing tomatoes, more frequently in the rotation was the likely cause of this increase.

Rust occurred every year on all safflower plots. However, it was not observed to cause yield loss, and thus no control treatments were applied. Corn smut was observed in all plots, but the level of its incidence remained below the treatment threshold.

Black mold on processing tomatoes was severe in 1989 as fall rains occurred prior to harvest. We applied mancozeb (Dithane) to conventional plots in an attempt to control black mold, but heavy rainfall made conditions too conducive for disease development, so it provided no noticeable control. Two types of black mold exist, one caused by Stemphyllium, associated with immature sunburned fruit, and the other by *Alternaria*, associated with mature fruit.



Stink bug damage, the white spots on the tomato shown above, at harvest was much higher in the organic and low-input systems than in either of the conventional systems.

Bacterial spot of processing tomato was severe in the spring of 1993, due to the rain and a hailstorm. Although many growers flew on a control treatment of copper hydroxide (Kocide), we did not because aerial applications to small plots were not practical. By the time the fields had dried sufficiently for a ground application, the weather was hot and dry, stopping the epidemic. No pesticide was applied.

Weeds. Percent cover of summer weeds varied by farming system, crop and year (table 4). With the exception of the organic corn plots in 1993, weed cover did not exceed 10%. The cultiva-

Higher populations of pigweed, a preferred host of the armyworm, seemed to aggravate pest problems for the organic tomatoes.

tor setup used varied according to the crop. In processing tomatoes, cultivation was done using a pair of disks, each set within 2 inches of the tomato seedline followed by L-shaped weed knives to clean the sides of the beds. Safflower and beans were cultivated using a rolling cultivator (Lilliston), while corn was cultivated with either a rolling cultivator or an in-row cultivator. Cultivation was not used in wheat or the cover crops. Cultivation generally removed over 90% of the weeds present. In processing tomatoes, hand weeding removed those weeds missed by cultivation. The value of the processing tomatoes justified the added expense of hand weeding (see pp. 34–42), whereas some weeds were tolerated in the other crops. The time required to hand weed plots varied, but on average took 1.5 to 2 times longer on the organic and low-input plots, where herbicides were not used. The shift to tomato transplants for the low-input and organic systems in 1992 and 1993 has not affected the difference in hand weeding time compared to conventional systems.

In the conventional corn plots, we prepared beds in the fall and eliminated emerged weeds by applying herbicide in the winter. A shallow cultivation prior to planting created a dust mulch (approximately 1 inch deep), and we planted corn seed into moisture below the mulch. Very few weeds germinated prior to the first irrigation. The vetch cover crop used on the organic and low-input plots partially depleted the soil moisture in the corn plots. Cover crop incorporation prior to planting caused further drying of the soil. Thus, corn on the low-input or organic plots either was irrigated at planting or required an irrigation much sooner than corn on conventionally treated plots, allowing weeds to germinate and compete with corn soon after planting. Thus, cultivation in the organic or low-input corn plots was only partially effective at uprooting weeds or burying those in the crop row. Large weeds, those almost equal in size to the corn at the time of first cultivation, were difficult to bury without burying the corn and had extensive root systems resistant to removal. In 1993, late spring rains prevented timely cultivation in the low-input and organic plots, resulting in weed cover approaching 40%. An application of 2,4-D (Weedar) controlled most of the escaped weeds in the low-input plots. Either 2,4-D or 2,4-D plus dicamba (Banvel) was used in all years except 1991 to control the broadleaf weeds that emerged in the low-input plots, while weeds persisted on the organic plots.

Weed cover generally varied more by year than by farming system (table 4). The late spring rains in 1993 allowed a greater number of weeds to emerge in most plots. This was particularly evident on organic corn and low-input or organic safflower, where hand weeding and/or herbicides were not used.

The method of weed control used in the farming systems resulted in spe-

TABLE 3. Insect abundance and damage recorded in corn and tomato organic (OR), low input (LI), conventional 4 year (C4) and conventional 2 year (C2) systems in 1989–1992

	1989				1990				1991				1992			
Crop and pest	OR	LI	C4	C2	OR	LI	C4	C2	OR	LI	C4	C2	OR	LI	C4	C2
Corn																
Aphids*	57.8	53.6	59.4	—	5.6	2.3	1.6	—	29.3	39.0	68.7	—	19.0	24.3	30.0	—
Aphid mummies*	43.8	50.8	36.3	—	0.6	0.0	0.0	—	0.0	0.0	0.0	—	0.0	0.0	0.8	—
Mites*	60.9	68.3	31.8	—	41.7	50.0	20.3	—	14.0	26.0	12.0	—	5.0	0.0	0.0	—
Corn earworms†	87.5	81.9	80.0	—	25.6	26.3	18.8	—	98.0	100.0	80.0	—	6.6	7.4	4.0	—
Tomato																
Potato aphids‡	59.4	42.6	20.3	17.8	14.6	15.3	14.4	16.7	15.0	34.2	19.2	55.0	32.0	34.0	10.0	12.0
Aphid mummies‡	8.7	3.9	4.8	3.4	3.3	4.4	1.9	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fruitworm eggs§	15.0	9.0	12.0	9.0	2.0	5.0	5.0	4.0	6.0	3.0	0.0	1.0	4.0	0.0	2.0	4.0
Parasitized eggs¶	31.8	40.0	36.8	25.0	12.5	0.0	0.0	0.0	45.5	75.0	100.0	80.0	0.0	100.0	0.0	0.0
Armyworm damage#	3.5	0.0	0.0	0.5	4.0	1.5	0.5	1.0	1.0	0.0	3.0	2.0	3.0	3.0	0.0	0.0
Fruitworm damage#	1.5	0.0	0.0	0.5	0.5	1.0	0.5	1.0	1.0	1.0	0.0	1.0	0.0	1.0	2.0	0.0
Scoreable damage**	0.9	0.5	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.4	0.4	0.4	0.3	0.4	0.4	0.0
Stink bug damage**	—	—	—	—	—	—	—	—	—	—	—	—	10.6	21.4	6.9	5.8

*Average percent infested lower leaves. Forty leaves per treatment per sampling date.
†Average percent infested ears. Forty ears per treatment replicate per sampling date.
‡Average percent infested leaves. Thirty leaves below highest open flowers per treatment replicate per sampling data.
§Number of viable eggs per 30 leaves below highest open flowers per treatment replicate at peak density.
¶Percent parasitized eggs per 30 leaves below highest open flowers per treatment at peak density.
#Average percent infested fruit at peak observed damage. Fifty fruit per treatment replicate.
**Percent infested fruit at harvest.

cies shifts among the systems. Most notable was the increase in barnyardgrass *(Echinochloa crus-galli)* in the low-input and organic systems. Barnyard-grass populations were extremely low at the beginning of this study due to previous weed control practices on this site. The pre-emergence herbicides napropamide, metolachlor and trifluralin (Devrinol, Dual and Treflan, respectively), used on processing tomatoes, corn and safflower in the conventional systems, were primarily grass herbicides that prevented the buildup of all grasses in these plots. Barnyardgrass can be effectively controlled by cultivation in the seedling stage, but the long seasonal germination period allowed this species to establish after the last cultivations and to set some seed prior to harvest, leading to its increase in the low-input and organic systems.

Purslane *(Portulaca oleracea)* was observed to be more prevalent on the low-input and organic plots in 1991. This succulent weed can remain alive on the soil surface for as long as a week and root again when the field is irrigated. Increasing the waiting period between cultivation and irrigation reduced this weed in the organic and low-input plots during 1992 and 1993.

Several weeds became more prevalent on the conventional plots compared to the low-input or organic plots. Field bindweed *(Convolvulus arvensis)*, a perennial, increased on the conventional 2-year rotation plots. The herbicides used in processing tomatoes were not effective against this species, and the fallow period following wheat allowed further growth. The reduced tillage on these plots relative to the others in this study may also have been a factor in the increase in field bindweed, as observed in numerous midwestern studies when converting to minimum or no tillage. Two other weeds observed to have increased on conventional plots were nightshade *(Solanum* sp.) and annual sowthistle *(Sonchus oleraceus)*. Both of these annual weeds also tolerate herbicides used in processing tomatoes and safflower. Nightshade can resemble tomatoes in the seedling stage and is often missed by hand weeding crews. Because herbicides suppress many weed species, those weeds that escape control are able to grow without competition.

TABLE 4. Weed cover in July, 1991 and 1993 relative to farming system and crop

Farming system	1991	Escaped* species	1993	Escaped species
	%		%	
Tomatoes				
Conventional	0.2	Pig	5.5	Pig/night/sow
Short rotation	0.2	Pig	7.5	Pig/night/sow
Low input	0.4	Pig/purs	6.5	Pig/BYG
Organic	0.8	Pig/purs	6.8	Pig/BYG
LSD .05	ns‡	ns		
Corn				
Conventional	0.5	Pig	2.8	Pig/night
Low input	1.8	Pig/purs	1.4	BYG
Organic	3.5	Pig/purs	36.2	Pig/BYG/lamb
LSD .05	2.4		4.9	
Safflower				
Conventional	0.4	Pig	0.2	Lamb/sow
Low input	0.5	Pig/purs	3.8	Lamb
Organic	0.8	Pig/purs	7.2	Lamb
LSD .05	ns	4.2		
Oats/Vetch & Wheat †				
Conventional	0.0		3.0	Vol. wheat
Short rotation	0.0		7.8	Bind
Low input	0.0		4.4	Vol. oat
Organic	0.0		2.9	Vol. oat
LSD .05	ns	ns		

* Bind = field bindweed, BYG = barnyardgrass, Lamb = lambsquarter (*Chenopodium album*), Night = nightshade, Pig = pigweed species (*Amaranthus retroflexus* and *A. blitoides*) , Purs = purslane, Sow = annual sowthistle, Vol. oat = volunteer oat, Vol. wheat = volunteer wheat,

† Field recently disced in preparation for bean planting in 1991. Data source: table 2 Pesticides and application rates (lbs a.i./a) used in each system.

‡ ns indicates no significant difference

Pest conclusions

The shift from conventional to low-input or organic pest control did not result in large increases in relative abundance of most pest species over the period of this study. However, there were some significant short-term problems in individual farming systems. Significantly greater damage occurred to organic and low-input plots by tomato fruitworm in 1989 and stink bugs in 1992, while insecticides prevented damage to conventional plots. Similarly, the cover crop residue appeared to increase damage by seed corn maggot to safflower and corn in two consecutive years.

The major long-term effects were on weeds. The wet spring in 1993 prevented timely cultivation and resulted in increased weed competition where herbicides were not used. The method used to control weeds differed among the systems and resulted in increases in barnyardgrass in low-input and organic systems and field bindweed and nightshade in conventional systems. The shift in weed species resulted in some further shifts in the control strategies, including herbicide changes or increased cultivation frequency, with little or no change in total weed cover.

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